Workshop - Towards an Alberta Fusion Roadmap

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Presentation to Fusion Workshops – Oct 25-26, 2013

Context for Today's Discussions

- Fusion energy will become important by mid-century (2050) or sooner (excepting Canada, much of the world is involved)

- Rationale for Alberta involvement in fusion energy development: (i) fusion as a GameChanger; (ii) implications for Alberta; (iii) opportunities for Alberta; (iv) benefits for Alberta

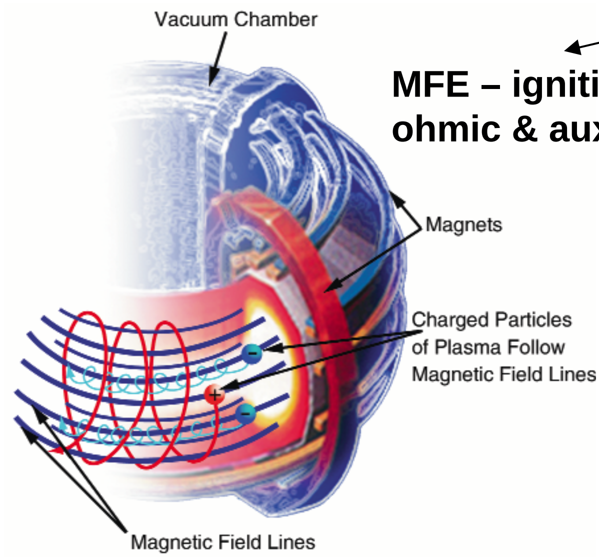
- Ways and Means for Alberta involvement (government, industry, R&D institutions) - identify possible objectives and strategy (energy, enabling technologies, capacity building, leverage global networking)

Why is Fusion Energy Important?

- **Increasingly, electricity is energy currency: (>40TW by 2100)**
- **Fusion is one of few sustainable, non-carbon solutions for fueling central power plants – major economic impact**
  - fission (sustainable only with fuel breeding, leaves waste)
  - fusion (sustainable, primary energy source, electricity/heat/H_2)
  - renewables (sustainable, secondary energy source)
- **Fusion applications**
  - base-load electric power generation
  - heat for thermal/chemical processing, etc.
  - production of hydrogen/synthetic fuels
  - desalination of sea-water
  - clean-up fission waste (transmutation of radioactive nuclides)

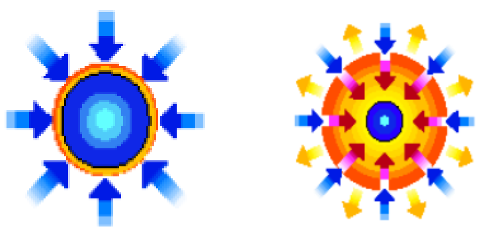
Why is Fusion Difficult?

- **Need high temperature for ignition** (T > 100,000,000 degrees C)
- **Need confinement for net energy** ($n_i\tau_E > 2\times10^{20}\ m^{-3}\ s$)
- Burning occurs when heating is self-sustained (by helium from fusion)
- Two confinement approaches: (i) **magnetic (MFE)**; (ii) **inertial (IFE)**



MFE – ignition requires ohmic & auxiliary heating

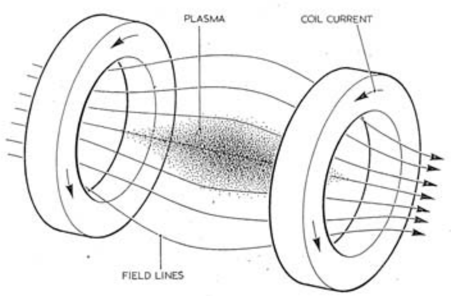
IFE – ignition requires driver beams to heat & compress target

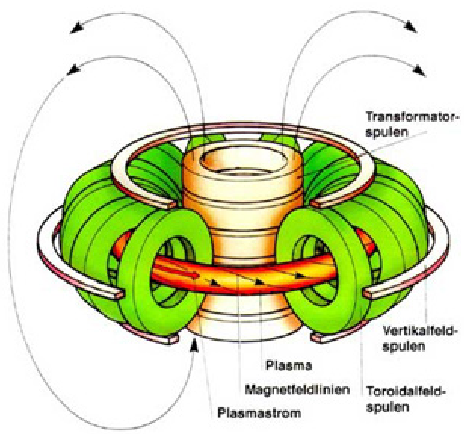


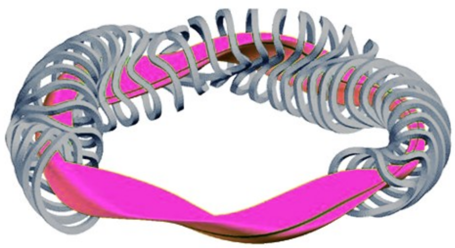
Fuel Burn

MFE – Some Approaches

Solenoids-Pinches | **Tokamaks** | **Stellerators**







Magnetic mirror – simple concept

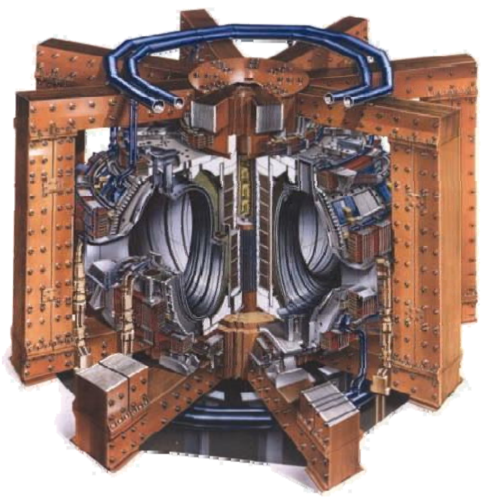
Pulsed operation w/o self-heating

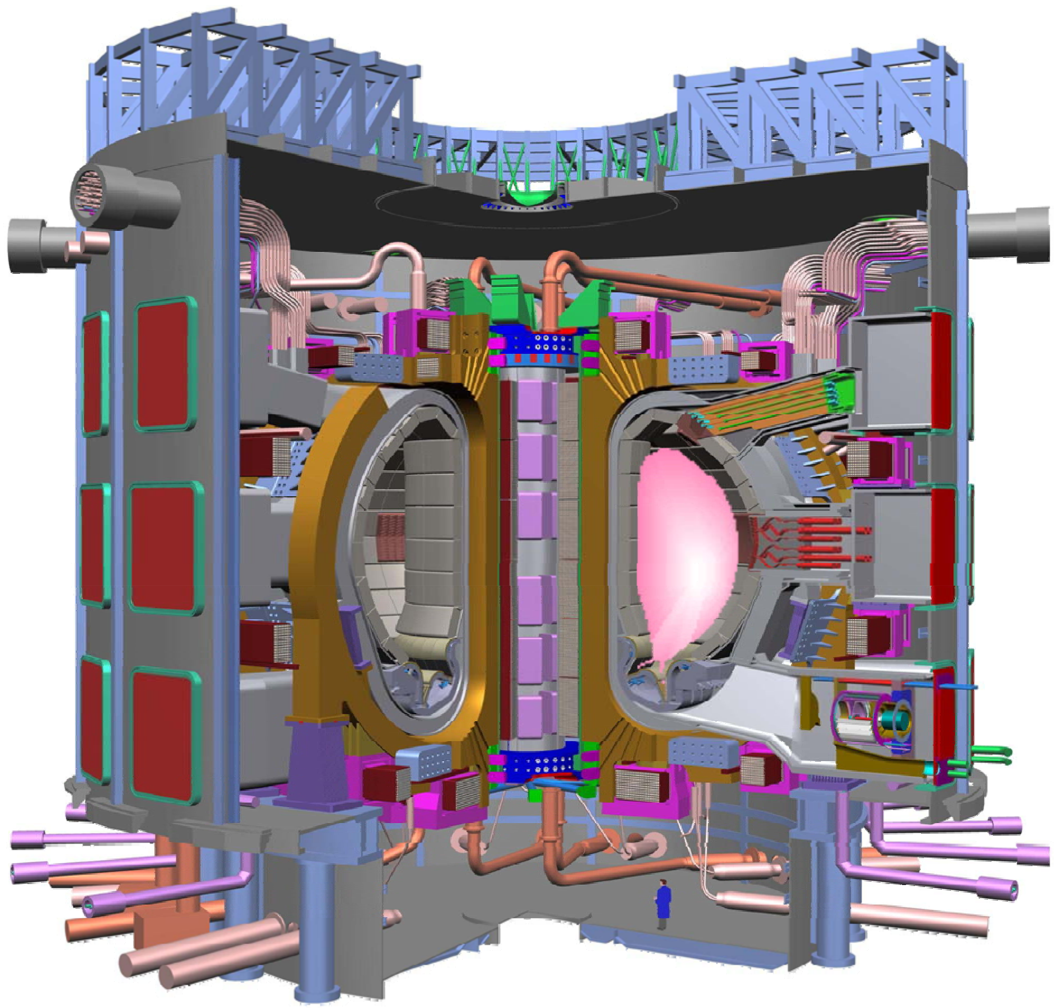
Steady-state but complex fields

Tokamaks - ITER

ITER – 1,000 m^3
P = 500 MW; Q=10
τ=400 sec

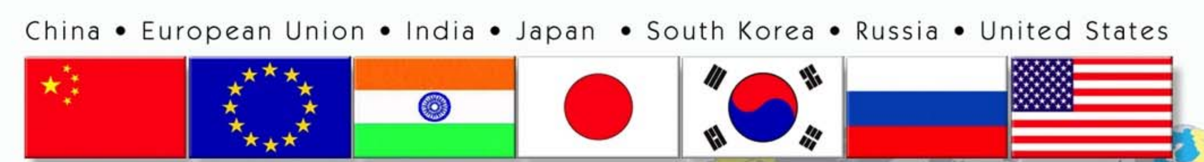
JET – 100 m^3
P = 16 MW; Q=0.65



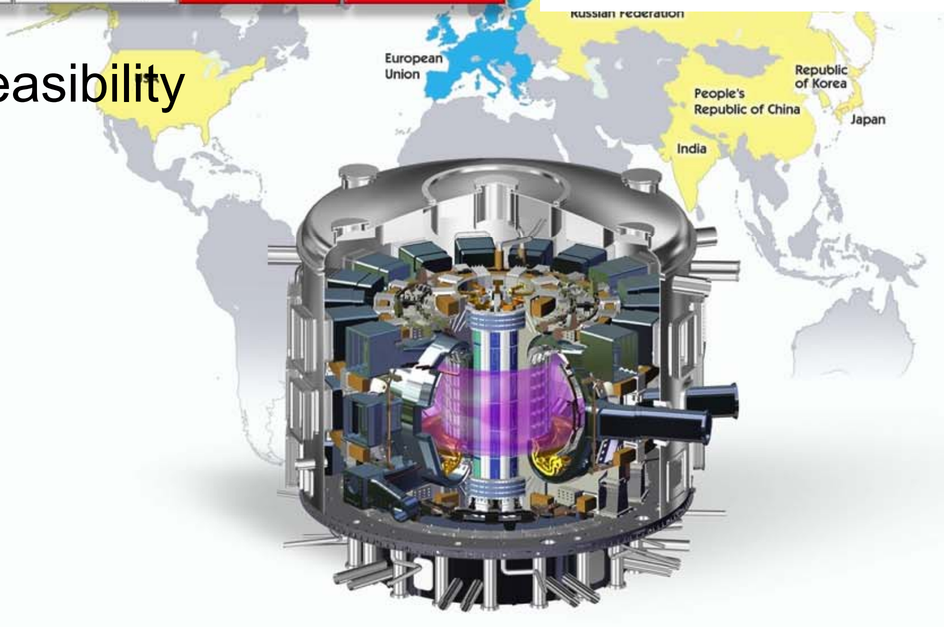


ITER – Global Initiative

Partnership: Seven nations jointly responsible for construction and operation



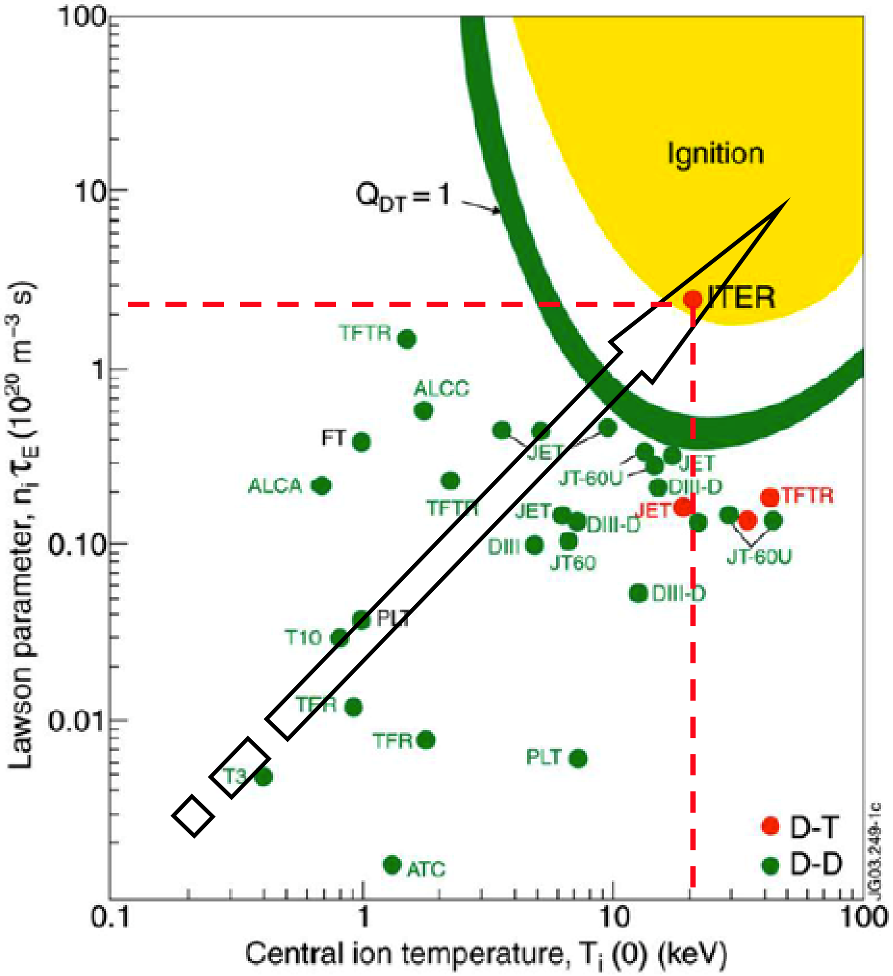
Mission: Demonstrate the feasibility of fusion energy



MFE – Site Visits

- Oak Ridge National Laboratory (US headquarters for ITER participation); major US nuclear materials science laboratory
- General Atomics (magnetic and inertial fusion); operates D-III Tokamak; fabricates targets for US inertial program (NIF, LLE)
- Culham Centre for Fusion Energy (UKAEA centre operates JET for EU; program is tightly linked to ITER planning)
- MFE has been widely pursued for 60 years; many national programs in addition to ITER collaboration; China & Korea fusion emphasis
- Confinement has been a key issue

Magnetic Fusion – Progress



International Tokamaks

Iter "The way" in Latin

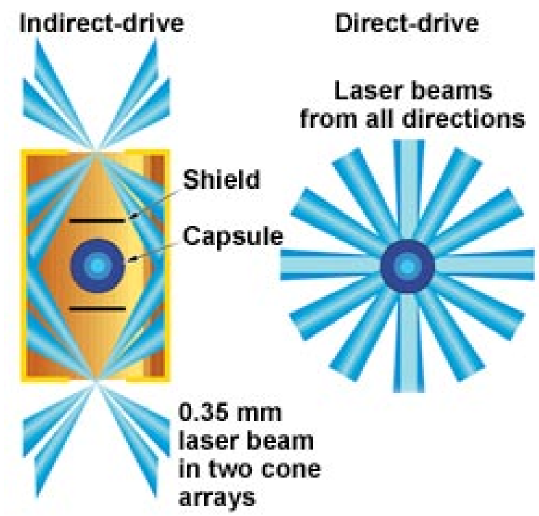
ITER explores the region of high gain (Q>5) and ignition

Tokamaks - ITER Timeline

- **Commission in 2022** – ITER plasma experiments until late 2027
- **D,T burning** (fusion) experiments in late 2027, early 2028
- Operate ITER as a fusion experiment for ~10-12 years
- Design and build **DEMO in 2040-2050** period – power to the grid
- Design and build auxiliary devices for material science studies
- **China has 2030's objective** for fusion power plant – push timeline

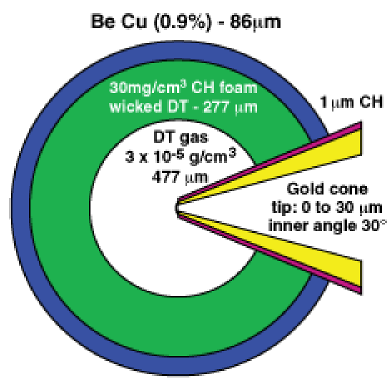
IFE – Some Approaches

Central Ignition



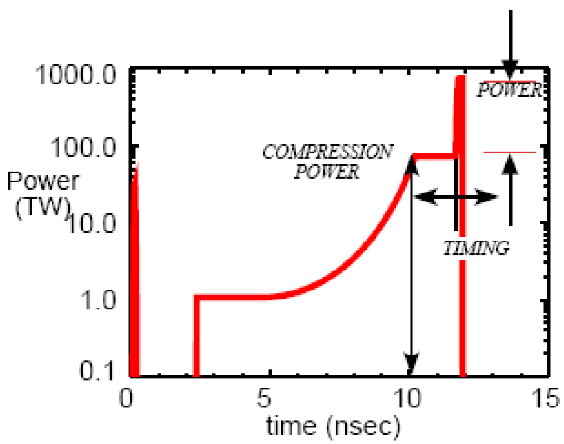
Uses shaped laser pulse

Fast Ignition



Uses PW, ps pulse

Shock Ignition



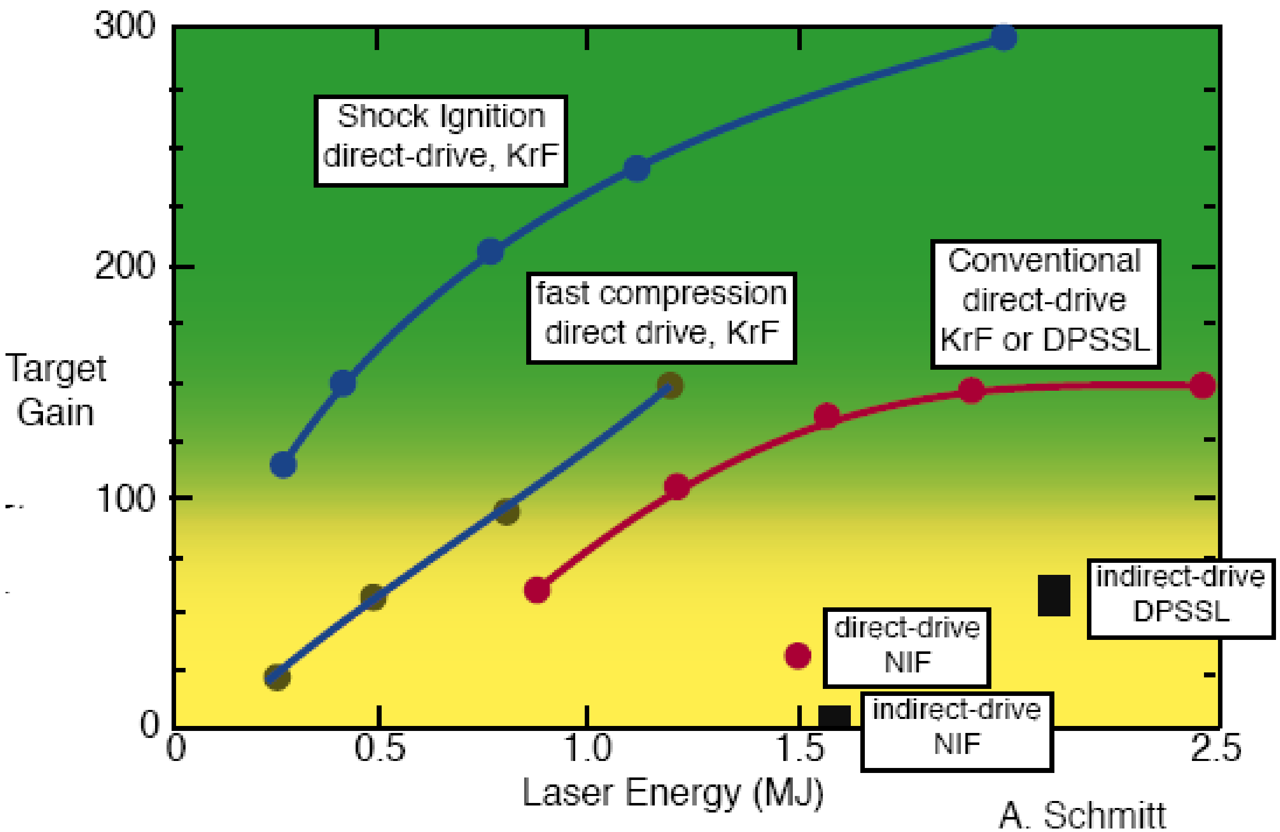
Uses high power peak at end of shaped pulse

Status of Drive Approaches

- **Indirect drive (LLNL)**
  - most developed, ignition close but not yet achieved
  - inefficient energy coupling (lasers to x-rays, more complex physics)
  - modest energy gains and yields predicted
- **Direct drive (LLE)**
  - not as developed as indirect drive (less funding historically)
  - efficient coupling (simpler physics)
  - higher energy gain
- **Direct/Indirect drive plus: fast ignition (ILE), shock ignition (LLE)**
  - less developed, possibility of much higher gain
  - smaller, more economic fusion systems

- **Bottom Line**
  - ideal system will evolve as some combination

Potential Economic Implications



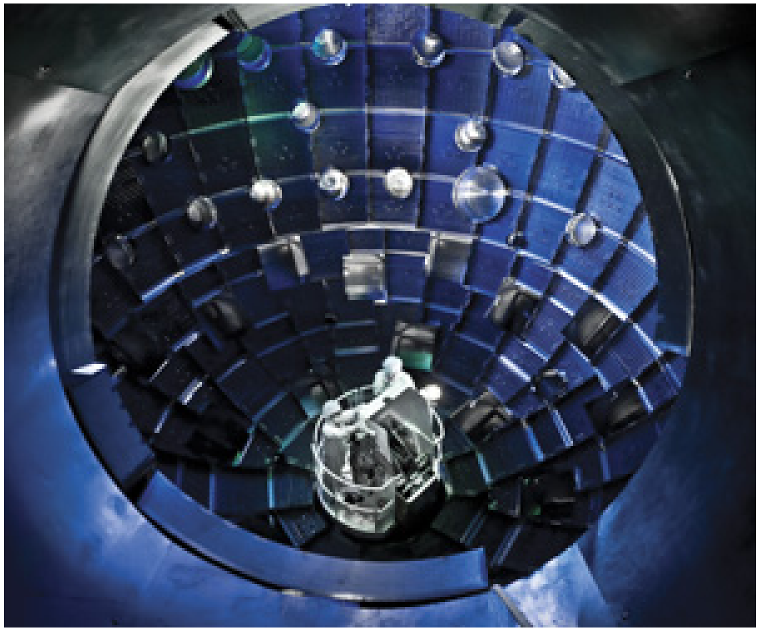
Laser driver is a major capital cost item

National Ignition Facility (NIF)

Advanced solid state lasers will reduce the footprint > 10 times

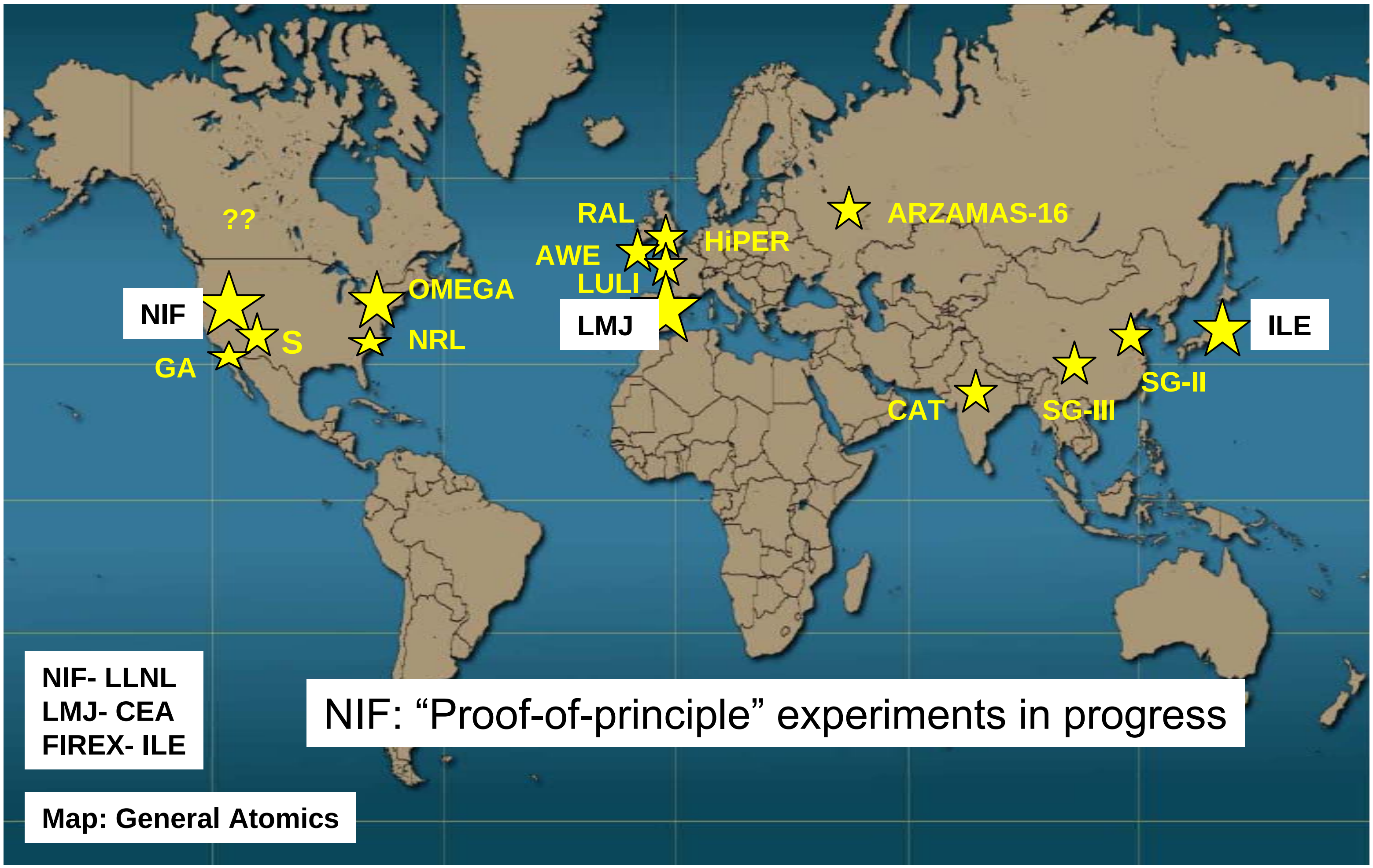
NIF Laser Bay/Target Chamber

View of 1 of 2 laser bays
192 laser beams; 1.8MJ; 500TW



Target chamber – 10m diameter

IFE - Global Initiative

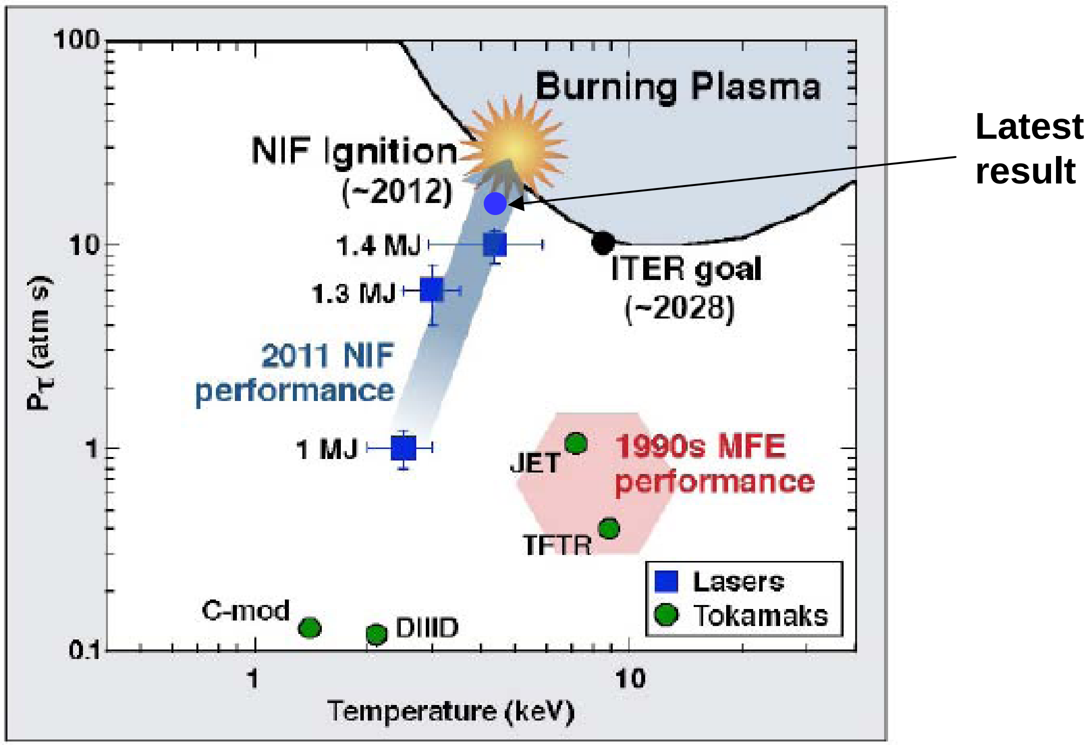


IFE – Site Visits

- Institute of Laser Engineering, Osaka University; national centre for inertial fusion in Japan focusing on direct drive and fast ignition
- Hamamatsu Corporation (building industry capability in enabling technologies and applications for inertial fusion)
- US Naval Research Laboratory (building capability for direct drive using KrF gas lasers)
- Lawrence Livermore National Laboratory (National Ignition Facility); traditionally, the largest inertial fusion program (indirect drive)
- Rutherford Appleton Laboratory (houses Central Laser Facility for high power laser research in UK); coordinator for EU HiPER planning
- LaserMegaJoule (CEA facility in France comparable to LLNL)
- Laboratory for Laser Energetics, Univ of Rochester (direct drive and alternative concepts)

Inertial Fusion - Progress

NIF is designed to provide full-scale evidence of fusion performance in the near future

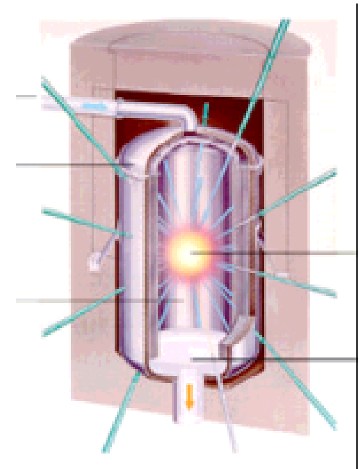


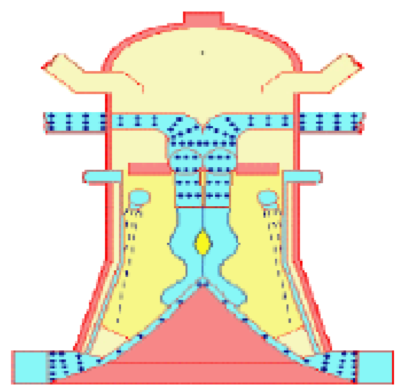
Uniquely, NIF provides the full-scale platform to allow direct progression to a power plant

IAEA roadmap to Inertial Fusion Energy

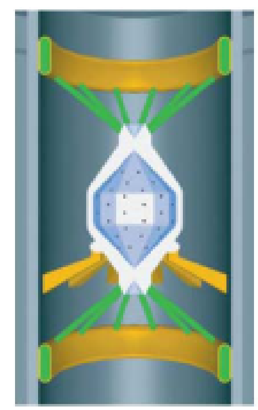
Road Map toward IFE Power Plant

2005
2010
2015
2020
2025
2030
2035
20xx
Ignition
Power production
Commercialization
NIF
LMJ
FIREX-I
FIREX-II
Physics on Beam Plasma Matter Interaction and HEDP
Concept Design
Engineering Design
Demonstration of Power Production
Design
Demonstration plant
Integrated system
Driver development
Advanced Laser technology
Fuel pellet fabrication, injection, tracking
Reaction chamber, blanket
Power plant technology, ESE issues





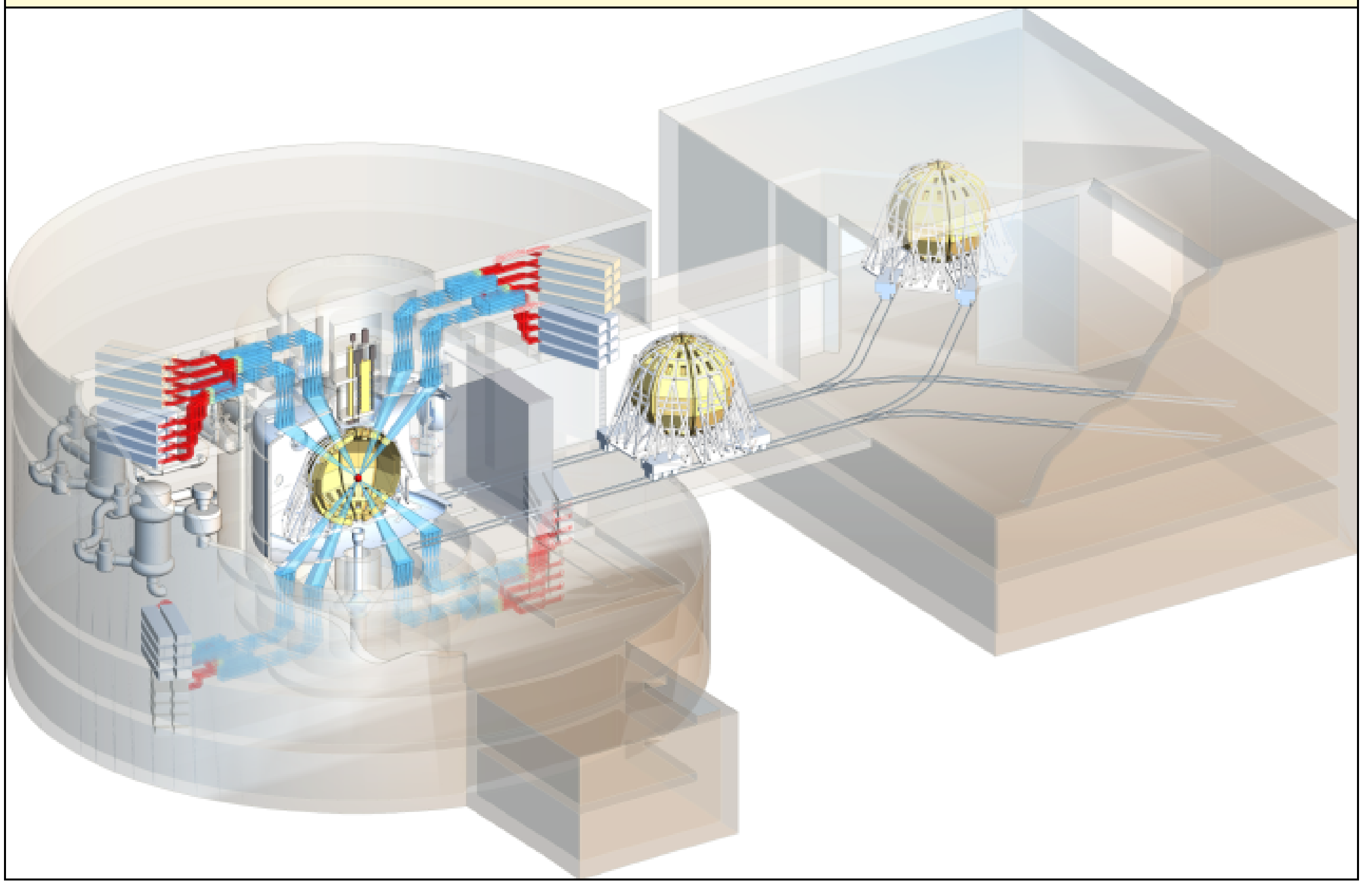
HYLIFE-II



SOMBRERO

LIFE – Power Plant Demo

Unsealed chamber, separate from the vacuum and optical systems



Chamber can be transported for maintenance or replacement

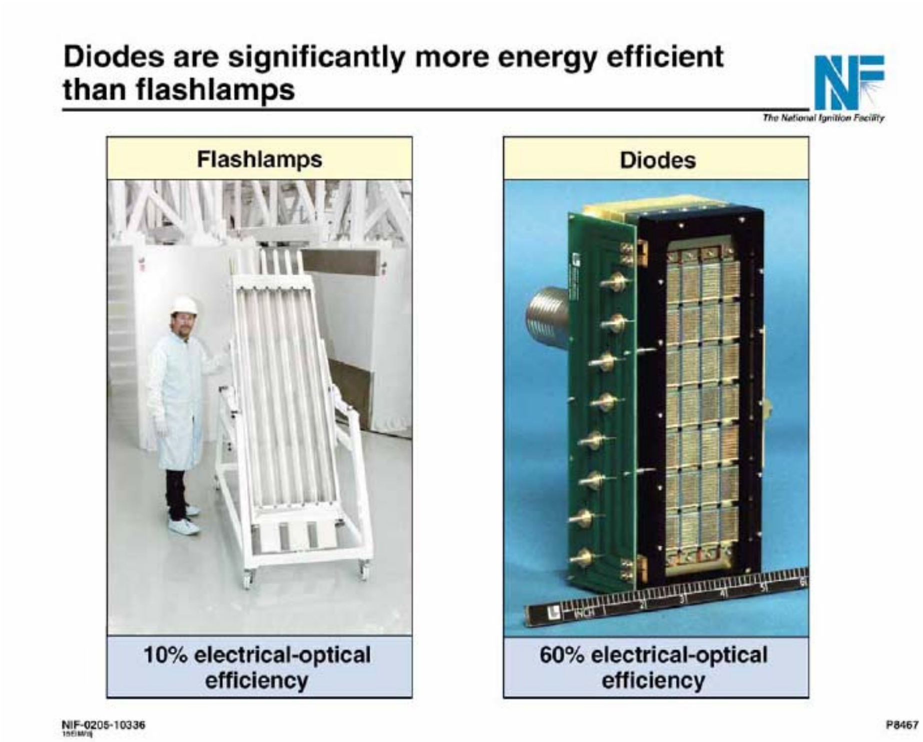
Some Key IFE Technologies

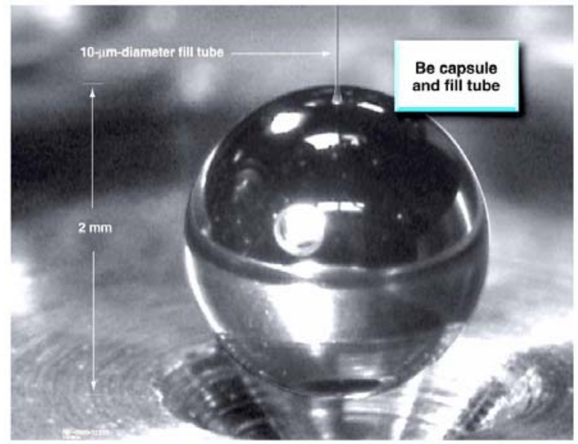
Inertial fusion R&D is a major driver of innovation

– Canada could benefit economically from overarching technology driver

- **High power lasers** (diverse applications)
- Precision optics and opto-electronics
- **Photonics** (superseding electronics)
- Sensors, instrumentation and data processing
- **Nanotechnology** (lasers, optics, targets, chamber materials)
- Supercomputer modeling (fusion scientists were pioneers)
- **Particle beam production & acceleration** (medical applications)
- High energy density physics (laboratory astrophysics)
- **Robotics** (remote handling, line replacement modules)
- Power systems engineering (intellectual property)

Inertial Fusion – Technology Impacts





Lasers, targets, optics, sensors, controls, systems engineering

Summary & Opportunity

- Controlled fusion ignition will be achieved in the near future (MFE and IFE)

- Demonstration fusion power plant:
  IFE (20 yrs; LLNL says 10 yrs)
  MFE (30 yrs; China/Korea/Japan could push agenda to 20 yrs)

- Opportunity & leverage for Canada: strong international support and working relationships (enables: manpower ramp-up; collaborative R&D; “watching brief”; identifying niches)

- Alberta has opportunity to take Canadian leadership in IFE (and be the link to international programs)